Rating Convergence Measurement in Trust-based Multi-Stakeholder Consensus Decision-Making

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***Abstract*—In collective decision-making where several participants involved to agree on one selection, reaching the consensus among them is important but it is challenging when the participants have conflicting interests. Therefore, the influence that is based on the trust from one participant to another could be useful to make the others shift their interests to be similar to others. Shifting interest can be long term or short term depending on participants behaviors. In our decision-making framework, there are different rounds where participants interact by ratings. Each round creates a rating matrix. In this paper, we study the rating convergence by analyzing the rating matrix changes by measuring its perturbations in each round and find the effect of these changes on reaching the consensus when using a trust and without it. We built a simulation that generates several decision scenarios. Our result showed that the changes in the rating matrix under the trust improve reaching the consensus in term of decreasing the required number of round and increasing the consensus value. Moreover, our result showed that changing interest in a long term performs better than short term in term of number or rounds reduction.**

Keywords–Trust; Decision-Making; Multi-Stakeholder; Matrix perturbations.

I. Introduction

In the decision-making process where several stakeholders involved, we need a mechanism to reach an agreement specifically when the stakeholders have conflicting interests. In general, the humans' nature gives them the tendency to decide rationally by selecting the decision that gives them the maximum satisfaction according to the Rational Choice Theory [1]. However, in reality, people might have different interest. Therefore, relying on rationality makes reaching a consensus decision to be challenging [2]. As a result, the stakeholders could use the influence on each other using the assumption of the Social Influence Theory [3] to make their interest similar and in turn reach the consensus. In our existing trusted-based decision-making framework [4], the trust of the stakeholder is used to influence the others. The higher the trust the higher the reputation of the stakeholder. As a result, any stakeholder with a high reputation could influence the others in term of recommending decisions or even changing their interests [5]. Changing the interest can be short term or long term [2]. In this work, the short-term change of interest is done locally during the negotiation in each round but does not affect the future choices. The long-term change of interest is done in a way that affects the stakeholder current and future choices.

In multi-stakeholder consensus decision-making, there is a network of stakeholders who might or might not influence one another. They meet, propose solutions and modify them in several rounds to reach a solution that suits everyone. During these rounds, the stakeholders rate each other to declare their opinions regarding the proposed solutions and these ratings can later be translated to trust. As a result, due to the involvement of humans who interact during the negotiation, trust among them comes into the picture. Trust provides many benefits, such as extra information through the impression the stakeholders develop of each other over time in a particular context, which helps to reach the consensus [6]. Also, trust indicates the interests similarity among stakeholders. As a result, the stakeholders' reputations can be obtained from the trust. The more ratings, the better because they increase the amount of information available about the stakeholders. The longer the history, the better because it increases the chances of having more ratings. The fact of having the stakeholders come from different backgrounds, hold different expertise and not to mention the conflicting objectives makes the consensus decision-making to be challenging.

In this paper, we aim to study the rating convergence of our proposed decision-making framework [4] by studying the rating matrix perturbation. The consensus is achieved when either all the stakeholders propose the same solution or they all give the maximum rating to one solution. The trust is an influencer factor that lead the stakeholders to adjust their selections based on the trustworthy stakeholders guides. Such influences may affect the rating behavior, as well as changing their initial interests they have in a way to be similar to the highly trusted stakeholders.

This paper is organized as follows. In Section II, we list the existing related works. Then, we show our trust model and the generic decision-making framework in Sections III and IV. In Section V, we address rating convergence measurement. After that, we explain the experimental setup and results in sections VI and VII. Finally, in Section VIII, we conclude the paper.

II. Related Work

Interactions among stakeholders when they make a collective decision is important since they negotiate while they are seeking for a solution to choose. In decision-making framework that uses machines to moderate the stakeholder negotiations, the interaction could be rating or even written comment to express the others opinion regarding the individuals choices and preferences [7]–[9]. Such notion of preferences occurs in decision-making field [2]. The individuals' preferences can be changed over the time due to the changes in the interests.

Those interests change can be a result of the influence by the others [6], the choices made before or even other factors that are based on the individuals situation at the time of making selection. Several studies showed that the individual interest and preferences are changing [5] [6] [10]–[15] and these study are different in term of the causes that lead changing the preferences. In [12], they predicted the changes in preferences based on the feedback of the negotiation process. Hansson [13] presented the dominant theories of belief change that may be called input-assimilating models. They expressed how the subject's belief state is transformed upon assimilation of an input. In addition to the different factors that change the individuals' preferences, the choices proposed while making a decision may affect the preferences or in other word, it shapes them [15]. Babajide and et al. [6] explained the change in the initial preference of an individual to match the others choices, either through coercion from others or selection by the individual team member. Preferences changes can be short or long term [2] [5] [16] [17]. Short term preferences affect the current choices while negotiating but the long term one affects the choices in the future. In social psychology field where they study the peoples' behavior, there are different theories that predict the preferences changes. For example, dissonance theory [10] [18] [19] motivates individuals to change their preferences to match their prior decision that can be a result of a selection they made in the past based on influence.

III. Trust

In reference to Alfantoukh and et al. [4], trust is a result of meeting expectations in a particular context. Therefore, there is no universal definition of trust because it is context-dependent [20]. We may represent trust as the level of an individual's agreement with a proposed solution due to the interests associated with it. We model trust by using the solution ratings during the agreement. Trust can be classified as local trust and global trust. Global trust is modeled by using all the historical interactions between any two individuals, which creates the stakeholders' reputations that can be used as a weight to influence other decisions. The local trust consists of current negotiation interactions between any stakeholders and it is used for updating the global trust. We have proposed a trust system based on the measurement theory [21]–[30]. This trust system has three stages: trust modeling, trust management, and decision making. The quantification of trust has been taken care of in the trust modeling and management phases. In our trust system, we define two metrics, impression and confidence, as continuous values in [0, 1]. The impression m shows the stakeholder's usefulness by evaluating his/her decision. Every two stakeholders have several interactions at different times, which lead to a distribution of their impressions of each other $M = \{m_1, m_2, \dots, m_k\}$. The impression value is the mean of the distributions (1). The other metric, confidence c, shows the degree of certainty about the judgments. The confidence of the judgment is obtained by knowing how far away from the real impression the stakeholder can be (2), where r is equivalent to the square root of the standard error.

$$m = \frac{(\sum_{i=1}^{i=k} m_i)}{k} \tag{1}$$

$$c = 1 - 2 * r \tag{2}$$

IV. Multi-stakeholder Decision-Making Model Based on Trust and Risk

We have designed a generic framework for multi-stakeholder decision making based on trust and risk that produces a decision agreed upon by the participants [4]. In this framework, the stakeholders negotiate with each other by 5-star rating to declare their agreement regarding the other solutions. The process starts with the stakeholder proposing their solutions that have corresponding interest value is calculated by the utility function. This utility function is context-dependent. The trust relationship among stakeholders construct the network of them. Those trust values form the reputation of the stakeholders. The trust is computed by our existing trust system [4] [21]–[29] that is based on measurement theory. Next, the stakeholders rate each other to declare their opinions of the proposed solutions. Then, the Group Decision making Model (GDM) entity aggregates those ratings. After that, the aggregated rating values of the solutions are ranked descendingly. The consensus level is obtained by the aggregated rating values. Therefore, the top value should have a value higher than or equal to a threshold value to indicate that consensus is achieved. Otherwise, a new round will start.

A. Rating

If we assume that the rating system is 5-star rating and stakeholder a rates stakeholder b, then the rating will depend on how far the a's interest of its own decision from the interest he gets from what b proposed. If b's decision give more interest to a than what a's proposed then the rating is the maximum, 5 stars. Otherwise, we consider the differences between the interest of decision proposed by a and the interest of decision proposed by b. The larger the difference the lower the rating and vice versa. Therefore, to compute the star rating associated with the difference, it requires to transform the difference value range ($diff$) to 5-star value range. $diff$ range is [0,1] and the start range is [0,5]. However, since the larger difference means lower rating, we need to find the transformation function, $f(diff)$, from [1,0] to [0,5], meaning to find value $rate$ in [0,5] associated with value $diff$ in [1,0]. If we assume the function to be linear, we may use the affine transformation function to find the rating from the differences. Using the affine transformation function, we can calculate the rating using (3)

$$f(diff) = 5 * (1 - diff) \tag{3}$$

B. Aggregation

The outcome of the rating's phase is the rating matrix. Suppose that there is a set of stakeholders, S, a set of decisions, D, and a set of corresponding trust values for each stakeholder. The stakeholders rate each other as represented in matrix R. In this matrix, the element r_{ij} represents the rating from stakeholder i to stakeholder j regarding j's proposed solution. Each stakeholder has an assigned trust value represented in the vector T. The sum of the trust values is W. The rating weighted average operator is RWA and computed by using R, T and (4). Here, the trust T is used to weigh the ratings. The outcome is a vector of consensus degrees corresponding to the proposed solutions. The selected decision is the decision with the maximum consensus degree, which is later compared to consensus threshold to check the consensus achievement.

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$$T = \begin{bmatrix} T_1 & T_2 & T_3 \end{bmatrix}$$
$$W = \sum_{n=1}^{3} T_n$$
$$R = \begin{bmatrix} 1 & r_{12} & r_{13} \\ r_{21} & 1 & r_{23} \\ r_{31} & r_{32} & 1 \end{bmatrix}$$

$$RWA = \frac{1}{W} * T * R \qquad (4)$$

V. RATING CONVERGENCE MEASUREMENT

As we indicated before, our framework generates rating matrices during the negotiation, the more the ratings the larger the magnitude of the matrices. Matrix norm can be used to measure the rating matrices magnitude and then use it to find the perturbations. For example, the Frobenius norm [31] can be used for calculating the ratings matrix norm by computing the square root of the sum of the absolute squares of each rating in the matrix. Suppose, the rating matrix is M and has elements r_{ij}, which each r_{ij} represents the rating from stakeholder r_i to the decision proposed by r_j and n is the number of decision makers, the Frobenius norm is computed by (5)

$$\parallel M \parallel_F = \sqrt{\sum_{i}^{n} \sum_{j}^{n} \mid r_{ij} \mid^2} \qquad (5)$$

The matrix norm shows how big the matrix is. Therefore, if the ratings become higher in every round then the matrix norm becomes larger than the previous round. Larger norms is an indicator of the ratings convergence to the consensus degree level. Our interpretation is that trust is an important factor to influence the stakeholders which leads to increase the matrix norm. To find the matrix perturbations, we use the difference of norms between the current round and the previous one. Supposed that there are three stakeholders s_1, s_2 and s_3 and three consensus degree values c_1, c_2 and c_3 stored in consensus vector, **c** respectively. The rating matrix R stores all the rating for one round.

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}$$

Let's assume there is a vector,**x**, of x_1,x_2 and x_3 which has a solution in the following linear system:

$$r_{11}x_1 + r_{21}x_2 + r_{31}x_3 = c_1$$
$$r_{12}x_1 + r_{22}x_2 + r_{32}x_3 = c_2$$
$$r_{13}x_1 + r_{23}x_2 + r_{33}x_3 = c_3$$

We can write the linear system above as:

$$R\mathbf{x} = \mathbf{c} \qquad (6)$$

Suppose that after one round, changes occurred, Δ. We write the rating matrix , R$\prime$ as:

$$R\prime = \begin{bmatrix} r_{11} + \Delta_{11} & r_{12} + \Delta_{12} & r_{13} + \Delta_{13} \\ r_{21} + \Delta_{21} & r_{22} + \Delta_{22} & r_{23} + \Delta_{23} \\ r_{31} + \Delta_{31} & r_{32} + \Delta_{32} & r_{33} + \Delta_{33} \end{bmatrix}$$

There is is a vector, **y**, of y_1,y_2 and y_3 such that

$$\mathbf{y} = \mathbf{x} + \Delta \qquad (7)$$

TABLE I. LIST OF THE PARAMETERS USED IN THE SIMULATION WITH THEIR CORRESPONDING VALUES.

Parameter	*Description*	*Value*
$NoSH$	Number of StakeHolders	15
$numbStakehoder$	Number of StakeHolders per project	5
$globalNoD$	Total number of decisions to propose	100
noS	Total number of samples	5
$pCount$	Number of Projects generated per sample	200
$roundCount$	Maximum Number of rounds per project	10
T	Trust Value range	[0,1]
$Interest$	Interest Value range	[0,1]
$consThreshold$	Minimum Consensus Degree	1.0

Also, each rating from i to j is changed such that

$$r_{ij}\prime = r_{ij} + \Delta_{ij} \qquad (8)$$

This victor has a solution in the following linear system:

$$r_{11}\prime y_1 + r_{21}\prime y_2 + r_{31}\prime y_3 = c_1 + \Delta_1$$
$$r_{12}\prime y_1 + r_{22}\prime y_2 + r_{32}\prime y_3 = c_2 + \Delta_2$$
$$r_{13}\prime y_1 + r_{23}\prime y_2 + r_{33}\prime y_3 = c_3 + \Delta_3$$

We can write the linear system above as:

$$(R + \Delta)\mathbf{y} = \mathbf{c} + \mathbf{\Delta} \qquad (9)$$

To compute the perturbation, we find the difference between **x** and **y** (6) and (9) using matrix (5) and vector (10) norms.

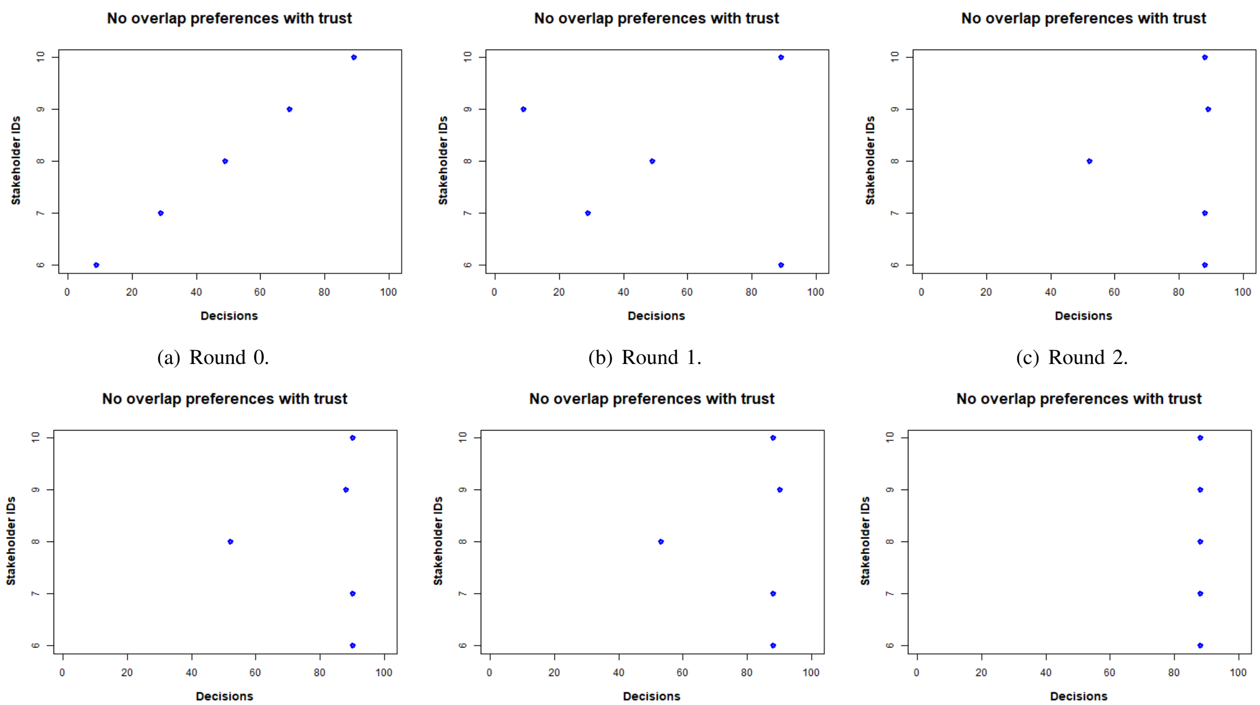
$$\mid v \mid_2 = \sqrt{\sum_{i}^{n} \mid v_i \mid^2} \qquad (10)$$

In the result section, we will present whether there is a correlation or not between the amount of perpetuation and the number of rounds to reach the consensus.

VI. EXPERIMENT

1) Experiment objective: The aim of the experiment is to study the ratings changes when several stakeholders want to make a decision and study the effect of the trust on those rating changes. Such an effect can be examined through the number of required rounds, the consensus degree average in each round, and the consensus achievements. We have designed and implemented a simulation to generate decision-making scenarios. We used a Netbeans framework with java language to build the simulation software. We created a database using derby and then linked it to the java program to store the data.

2) Experiment setup: In this experiment, we selected five users for each case of the interest overlap. So, for full overlap interests, we assigned IDs from 1 to 5 to stakeholder, for no overlap interests, we assigned IDs from 6 to 10 and finally for semi overlap, we assigned IDs from 11 to 15. Then, for each user, we stored the interest vales which is the rating he/she gives. For each interest overlap scenario, we created five samples and each sample has 200 selection project. Also, these projects were generated one time with trust and one without. Therefore, the total projects generated for each samples were 1200 projects. Additionally, we generated these projects under two assumptions: one with long term interest and the other is short term. Table I shows the parameter setup.



(a) Round 0. (b) Round 1. (c) Round 2.

(d) Round 3. (e) Round 4. (f) Round 5.

Figure 1. Stakeholders selections movement during the negotiation for no overlap case with trust

VII. RESULTS

In this section, we show the result of the decision making simulation. In this light, we present the stakeholders selections movement during the negotiation for one of the generated project of the no overlap case. Our evaluation criteria are changes of the rating norm, the consensus degree convergence, number of rounds and the correlation between the rating matrix perturbation and the number of rounds.

Figure 1 shows the stakeholders decisions movement for a project that took 5 rounds to reach the consensus. In round 0 (Figure 1(a)), all the stakeholders proposed different decisions. In round 1 (Figure 1(b)), stakeholder 6 changed his decision to be similar to stakeholder 10. In round 2 (Figure 1(c)), stakeholders 7 and 9 selected decisions closer to 6 and 10. In round 3 (Figure 1(d)), stakeholder 9 selected a new decisions closer to 6,7 and 10. Round 4 (Figure 1(e)) is similar to round 3. In round 5 (Figure 1(f)), stakeholder 8 changed his decision to be similar to the rest. Therefore, the consensus was achieved. Table II shows the percentage of the projects that reached consensus. Our result showed that applying the trust helped on increasing the consensus achievement. Moreover, the long term preferences performed better than short term. Similarly with the number of rounds (Table III). Table IV shows the rating matrix norm values and the consensus degree for the same project. The rating norm and the consensus kept increasing.

Figure 2 presents the changes in the rating matrix norm during negotiations. When considering trust, 82% of the interactions had the norm increased, 2% no change and 16% was decrease. However, without trust, the norm never increased neither decreased and it remained unchanged. Figure 3 presents the number of rounds for each project with trust for short-term preference 3(a) and long-term preference 3(b). It can be noticed that the number of round for no overlap and semi overlap never decreased without trust. However, the rounds can be decreased with trust and it is more decreasing for long-term preference compared with short-term preferences. The matrix perturbation has an effect on the number of round as there is a moderate negative correlation, -0.45. So, when the average

TABLE II. PERCENTAGE OF THE PROJECTS THAT REACHED CONSENSUS FOR LONG TERM AND SHORT TERM PREFERENCES.

(a) With Trust

Preferences	***Overlap***	***No overlap***	***Semi overlap***
Short term	100%	98%	92%
Long term	100%	99%	99%

(b) Without Trust

Preferences	***Overlap***	***No overlap***	***Semi overlap***
Short term	100%	0%	0%
Long term	100%	0%	0%

TABLE III. AVERAGE ROUND OF THE PROJECTS THAT REACHED CONSENSUS FOR LONG TERM AND SHORT TERM PREFERENCE.

(a) With Trust

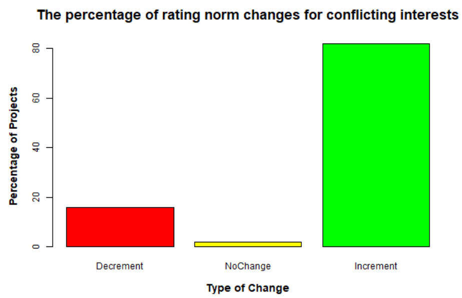
Preferences	***Overlap***	***No overlap***	***Semi overlap***
Short term	1	5	5
Long term	1	1	1

(b) Without Trust

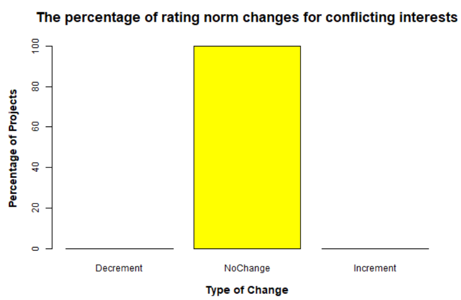
Preferences	***Overlap***	***No overlap***	***Semi overlap***
Short term	100	10	10
Long term	1	10	10

TABLE IV. RATING MATRIX NORM VALUES AND THE CONSENSUS DEGREE FOR ONE PROJECT.

Round Number	*Rating Norm*	*Consensus Degree*
1	3.098386677	0.81
2	3.666060556	0.88
3	3.794733192	0.89
4	3.752332608	0.92
5	4.507771068	1

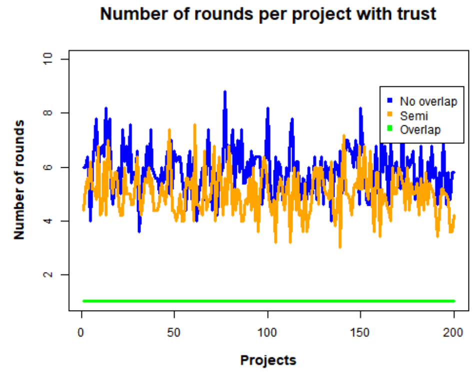


(a) With Trust

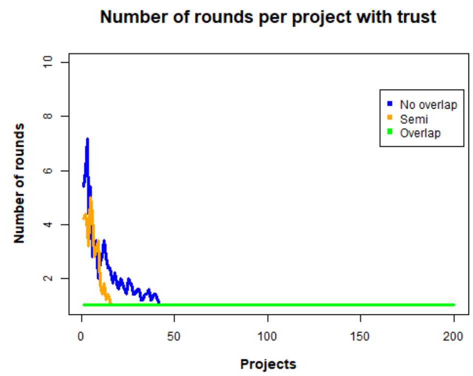


(b) Without

Figure 2. Rating matrix norm changes for no overlap case with trust and without



(a) With trust for short-term



(b) With trust for long-term

Figure 3. Number of rounds in each project for all the three overlap cases

perturbation is high then the number of rounds is decreasing. From the results, we found that:

- Trust helps the stakeholders to reach the consensus when conflicting interest exists by the influence from the highly trusted participants.
- Trust increases the rating matrix norm in most of the cases. Increase the norm means increasing the rating which leads to increase the consensus degree.
- Trust helps changing the preferences whether long-term or short term. Changing the preference in the long run helps to decrease the number of rounds later,
- Trust helps decreasing the number of project rounds except few cases, such as when a trusted participant has his decision liked by the others and then he changes his opinion frequently for the coming rounds.
- Trust helps to increase the rating changes which leads to increase the rating norm and the matrix perturbation.

VIII. CONCLUSION AND FUTURE WORK

In collective decision-making where several participants involved to agree on one selection, reaching the consensus among them is important but it is challenging when the participants have conflicting interests. The influence among them can help to eliminate this challenge. Such an influence can be obtained from trust of one participant to another. The trust is useful in changing the participants preferences whether it is a long or short term depending on participants behaviors. In this study, we apply our decision making framework that is based on trust for investigating the rating convergence during negotiation. We used the matrix norm as a measurement for obtaining the magnitude of the rating matrices and then find the perturbation accordingly. The larger the magnitude the more chances to reach the consensus. Our result showed that the changes in the rating matrix under the trust improve reaching the consensus in term of decreasing the required number of round and increasing the consensus value. Also, our result showed that changing interest in a long term performs better than short term in term of number or rounds reduction. Moreover, we found that there is a negative moderate correlation between the matrix perturbation and the number of round needed to reach consensus. For future work, we will validate the rating convergence measurement in a real application.

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